

Shock Heated Dust in L1551: $L(\text{IR}) > 20$ Solar Luminosities

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ABSTRACT. The infrared bolometric luminosity of the extended emission from the L1551 flow exceeds 20 solar luminosities. Ultraviolet radiation from the shock associated with the flow appears to heat the dust requiring shock temperatures from 10,000 to 90,000 K in L1551, velocities of ~ 50 km/s near the end of the flow, and a minimum mechanical luminosity of ~ 40 solar luminosities. The total energy requirement of the infrared emission over a 10,000 year lifetime is $10^{(46-47)}$ ergs, two orders of magnitude higher than previous estimates for L1551. Infrared radiation offers a new method of probing interstellar shocks, by sampling the ultraviolet halo surrounding the shock. At least one current model for bipolar flows is capable of meeting the energetic requirements.

I. Introduction

The extended infrared emission from dust around the L1551 flow reported by Clark and Laureijs (1986), is analyzed. Bipolar flows from young stars have heretofore been detected by means of broad wings on spectral lines (usually CO, or H α). The detection of infrared emission from dust surrounding bipolar flows offers a new method of observing such flows. From the extended infrared emission from the L1551 flow, the total infrared luminosity is calculated, the heating mechanisms is analyzed, the mechanical luminosity of the shock is estimated, and the energy requirements calculated over the lifetime of the flow.

II. Data

IRAS HCON3 survey data, CPC images, AO edge detector data, and HCON1, 2, and 3 raw detector data have been analyzed. We have examined the spatial extent and morphology of the infrared emission by analyzing GEISHA IRAS HCON1, 2, and 3 raw detector data, and small scale structure from CPC images.

III. Observed Flux, Dust Temperature, and Ambient Density

Table 1 illustrates the derived spatially resolved data from IRAS HCON3 survey data, shown as strip averages from northeast to southwest: spatial offset in arc minutes, IRAS flux, infrared luminosity, dust temperature (dust emissivity varying inversely with wavelength), and ambient density from Snell (1981).

The extended flux contains a small model correction for the contribution near IRS5 estimated with a cylindrical model which matched the observed cloud properties (Snell 1981, Snell and Schloerb 1985, and Mundt et al. 1985). $L(\text{IRAS})$ is the luminosity observed by the IRAS filters. The bolometric IRAS luminosity, corrected for that portion of a Planck curve with appropriate dust emissivity not detected by the IRAS detectors, is 20-29 solar luminosities (L_0), with the range representing uncertainty in dust emissivity, and dust temperature.

Table 1

Offset	F(60)	F(100)	L(IRAS)	T(dust)	n_0
'	Jv	Jy	Lo	K	cm ⁻³
-31.8	1.4	20.1	0.15	21	36
-26.5	1.0	22.8	0.17	20	52
-21.2	2.0	24.9	0.19	21	81
-15.9	6.1	30.0	0.23	29	143
-10.6	9.6	52.0	0.40	27	315
-5.3	19.8	192.3	1.47	25	1114
0	25.9	414.6	3.16	22	7295
5.3	15.2	238.6	1.82	22	1114
10.6	10.4	128.1	0.98	22	315
15.9	7.4	87.6	0.67	23	143
21.2	2.5	60.8	0.46	23	81
26.5	0.6	32.6	0.25	20	52
31.8	0.2	15.1	0.11	21	36

The extended infrared flux increases strongly towards IRS5, in good agreement with the model of Snell (1981), while the dust temperature is quite uniform across the flow. The comparison of the data near IRS 5 with the cylindrical model described above indicates a significant reduction in dust emission from near IRS5, perhaps from lower dust temperature, or less warm dust.

IV. Dust Heating Mechanism

The dust exhibits a near constant temperature of 22-26 K, with a radiative lifetime of days, requiring the dust heating source to be active at the present time. Three likely possibilities for heating the dust are: 1) radiative heating from IRS5, 2) mechanical heating from the neutral shock heated gas, and 3) radiative heating by shock-produced ultraviolet.

The uniform dust temperature over .5 to 2 pc speaks against the star as the heating source for the dust. Collisional heating of dust by hot post shock gas requires coexistence of the dust and hot gas which, under the range of conditions of interest to the L1551 flow, is less efficient at heating the dust than ultraviolet heating. The post shock region should have a thickness (.007 -.02 pc) which is small compared to the total width (0.4 pc), and the infrared emission should be strongly limb brightened for collisional heating.

The dust in the L1551 cloud surrounding the flow can be quite effective at trapping radiation which escapes from the flow. The conditions necessary to heat the dust by ultraviolet radiation from the shock in L1551 are estimated as an average shock temperature of 40,000 to 80,000 K, and an average shock velocity of 24 to 36 km/s (Hollenbach and McKee 1979). Ultraviolet heated dust will occupy the volume defined by the ultraviolet opacity reaching approximately 1. The surface of ultraviolet opacity = 1 (at 1500 Angstroms) has been modeled, and unveils the ultraviolet halo around the shock, producing a very distinctive morphology which blooms out at greater radii where the ambient density falls.

Figure 1 illustrates the observed infrared emission (solid), the CO flow (dotted) which coincides with the collisional heating morphology, and the UV heating morphology (dashed). UV heating offers a natural explanation of the excess infrared length and excess width at the ends of the infrared emission, although not of the excess infrared width near IRS5.

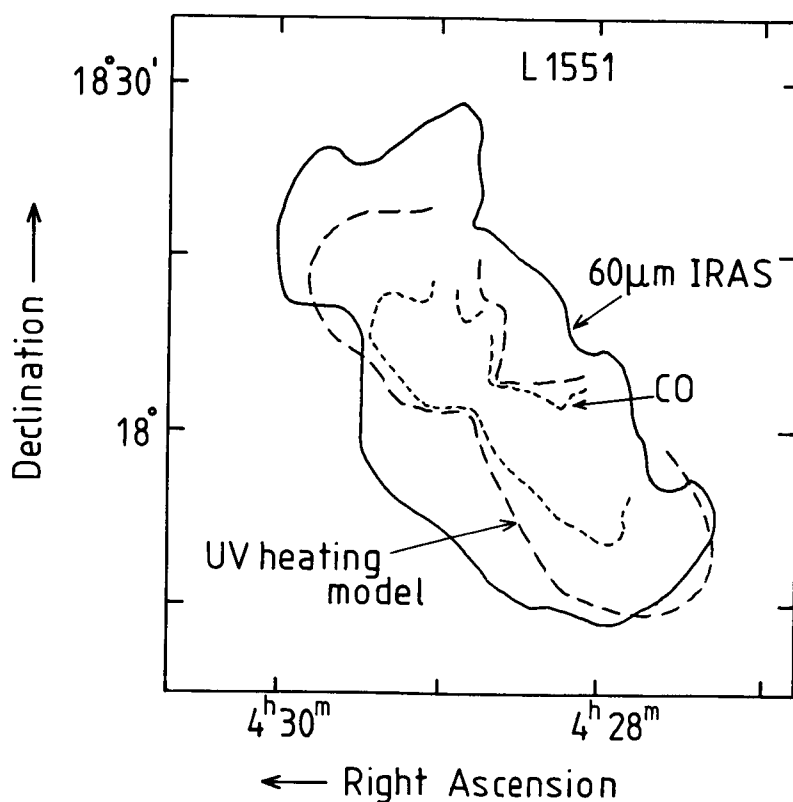


Figure 1. CO map - also the collisionally heated morphology (dotted), the ultraviolet morphology (dashed), and the observed infrared emission (solid).

Raw Detector Data - The raw survey detectors from HCON1, HCON2, and HCON3, which offer 1.5' resolution for the in scan direction, have been analyzed to determine the morphology with preliminary data from the GEISHA project. These confirm that the infrared morphology is as long and as wide as indicated by the IRAS survey data, and that the morphology of the infrared emission is that of a filled image with no suggestion of limb brightening, as predicted for ultraviolet heating of the dust.

V. The Mechanical Luminosity of the Shock

The dust heating has been modeled to determine the minimum heating requirements. The ultraviolet radiation field (Hollenbach and McKee) necessary to heat the dust requires shock temperature $\sim 60\text{--}90,000$ K at the low density end of the flow (2 pc out), falling to $\sim 10\text{--}18,000$ K within .3 pc of IRS5, with corresponding shock velocities of ~ 50 km/s and ~ 20 km/s, the variation presumably due to projection effects of the shock upon the ambient material. The mechanical luminosity is estimated as 40-140 L_{\odot} .

VI. The Mechanism Responsible for the L1551 Flow

The infrared luminosity of the L1551 flow is 20-29 L_{\odot} and the mechanical luminosity is estimated as 40-140 L_{\odot} . Emerson et al. estimate the bolometric luminosity of IRS5 as 38 L_{\odot} , and Mundt et al. classify IRS5 as a G-K star. These data indicate that IRS5 may not be energetically capable of providing sufficient energy to radiatively drive the L1551 flow (Draine 1983). A luminosity range of 20-140 L_{\odot} over a flow lifetime of 10^4 years implies an energy of $>10^{46-47}$ ergs, two orders of magnitude larger than previous estimates (Snell and Schloerb). Several times 10^{48} ergs is released in the collapse of a solar type star to the main sequence, and the model of Draine (1983) easily converts energies of this order via a magnetic bubble which can drive flows. The L1551 infrared parameters place L1551 well within Draine's two asymptotic limits on his figure 7.

VII. Summary

The detection of extended infrared emission from the L1551 flow offers a new technique for probing bipolar flows, and a new method of estimating the energetic requirements of the flows. The infrared luminosity is 20-29 L_{\odot} . The dust appears to be heated by ultraviolet radiation from the shock requiring velocities ~ 50 km/s. The infrared dust emission appears to unveil the ultraviolet halo around the L1551 shock. The shock mechanical luminosity is estimated as 40-140 L_{\odot} . Over a 10^4 year lifetime, this presents an energy requirement of 10^{46-47} ergs, two orders of magnitude larger than previous estimates. The magnetic bubble model for the bipolar flow is capable of supplying energies of this magnitude.

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